Comparison of Three Insect Sampling Methods in Sweetpotato Foliage in Mississippi[1]

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Abstract Three sampling methods—sweep-net, hand-vacuum modified from a leaf vacuum/blower, and a wheeled, blower-vacuum designed to blow insects from the foliage into the vacuum port of a leaf vacuum—were compared as methods for sampling insects in sweetpotatoes, *Ipomoea batatas* L. Results of the 4-yr study at 2 locations in Mississippi showed that the number of insects collected by the blower-vacuum method was lower than the number collected by the other 2 methods. Although results differed with different insect species, the numbers of insects collected in hand-vacuum samples were usually greater than or equal to those collected in sweep-net samples during the first few weeks after planting, but less than those in sweep-net samples late in the season. Based upon these results, sweep-nets are the preferred method for season-long sampling of insects in sweetpotatoes.

Key Words sweetpotato, sampling, insects, sweep-net, vacuum

Sweetpotatoes were planted on 39,255 ha in the U.S. in 2008, and Mississippi ranked third among states producing significant amounts of sweetpotatoes, with production of over 18% of the nation's gross sweetpotato product of 18,345,000 cwt (Anonymous 2009). Insect pests found in sweetpotato foliage in Mississippi are similar to those found on the crop in other midsouthern states. These include several chrysomelid beetles (Coleoptera: Chrysomelidae), namely tortoise beetles (*Agroiconota bivittata* [Say], *Charidotella sexpunctata bicolor* [F.], *Chelymorpha cassidea* [F.], and *Deloyala guttata* [Olivier]), cucumber beetles (*Diabrotica balteata* LeConte and *D. undecimpunctata howardi* Barber) and flea beetles (*Chaetocnema confinis* Crotch, *Systena frontalis* [F.], and *S. elongata* [F.]); scarab beetles (Coleoptera: Scarabaeidae) (*Phylophaga* spp. and sugarcane beetles (*Eutheola humilis rugiceps* [LeConte])); click beetles (Coleoptera: Elateridae) primarily of the genera *Conoderus*, *Heteroderes* and *Melanotus*; whitefringed beetles (Coleoptera: Curculionidae) (*Naupactus leucoloma* Boheman and *N. perigrinis* [Buchanan]); sweetpotato weevils (Coleoptera: Brentidae) (*Cylas formicarius elagantulus* [Summers]), and numerous lepidopterous pests (Reed et al. 2009). Sampling for many of these species is

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recommended to determine need for application of insecticides to prevent insect damage to sweetpotato roots.

Sampling methods vary with different insect pests. Although kairomone attractants have been studied for sampling cucumber beetles (Jackson et al. 2005), sweep-net and vacuum samples are functional sampling techniques for these beetles as well as for adult click beetles, flea beetles, tortoise beetles, whitefringed beetles and lepidopteran larvae and adults in the sweetpotato foliage. Whitefringed beetles may be collected in sweep-net and vacuum samples, but visual examination of plants for adult insects or their feeding damage is also a sampling option (Zehnder 1997). May/June beetles may be sampled by light traps or pheromone traps (Diagne 2004) and may be occasionally collected in sweep-net samples. Sweetpotato weevils exhibit diurnal activity and are most active in the foliage during evening and night (Howard 1982), so they are not usually collected in sweep-net or vacuum samples. Currently, this pest is effectively sampled with pheromone traps (Jansson et al. 1993). Aphids and white flies are probably best sampled with sticky cards or visual observation.

The relationship of insect population dynamics with insect-damaged sweetpotatoes has been demonstrated for several species in different areas. Crop profiles for sweetpotato from Louisiana (Hammond et al. 2001), Mississippi (Byrd et al. 1999), and North Carolina (Schultheis et al. 2005) listed thresholds for insecticide applications for some insect pests based on crop damage related to numbers of insects in sweep-net or other sample methods. The importance of being able to confidently sample for insect pests in the sweetpotato fields is critical for successful insect pest management.

In general, sweep-nets have been the tool of choice for IPM practitioners in sweetpotatoes because of low price, ease of use, and low maintenance. Gasoline-powered, hand-held vacuums (hand-vacuum), and blower-vacuum devices (blower-vacuum) using leaf blower motors mounted on bicycle-wheeled frames with the exhaust air blowing across the sweetpotato foliage into a screen on the vacuum side of the device also have been used to sample sweetpotato insect pests (Reed and Williams 2004).

Hand-vacuums, blower-vacuums, and sweep-nets have been used by researchers working independently in different areas of Mississippi. In the primary sweetpotato production area of the state centered near Vardeman, MS, located in the northeastern portion of the state known as the Hill region, sweep-net samples were compared with hand-vacuum samples during 2005 as part of ongoing research projects. In a separate study in 2003, sweep-net, hand-vacuum, and blower-vacuum samples were evaluated in this area (Reed and Williams 2004). In the Delta area of the state, sweetpotato fields were sampled with at least 2 of the 3 sampling procedures each year for 4 yrs. Our objective herein was to summarize these studies in the 2 regions of Mississippi comparing sweep-net, hand-vacuum and blower-vacuum sampling methods for sweetpotato production.

Materials and Methods

Sampling devices. Hand-vacuums were modified ECHO Shred 'N' Vac ES-210 (Hill Region study) or ES-230 (Delta study) leaf vacuum/shredders (Echo, Inc., Lake Zurich, IL) (Fig. 1). These were adapted to vacuum insects by inserting a holding cup with a 50-mesh nylon screen bottom (Fig. 2) into the end of the suction pipe. Hand-vacuums were used during 2002 and 2003 to sample insect pests in sweetpotato small plot trials at both locations. The method involved walking slowly down a row of

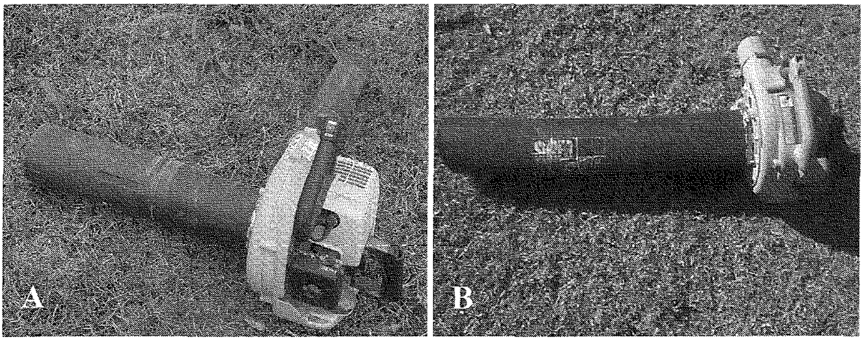

Fig. 1. Hand-vacuums used in the Delta Region study (A) and Hill Region study (B).

sweetpotatoes with the suction pipe being moved from side to side within the foliage. At the end of the sample area, the screen cup was removed and insects were counted in the field or transferred to a plastic bag for transport to the laboratory for identification and counting.

A blower-vacuum was designed in 2003 and used to sample insects in small plot sweetpotato insecticide trials. The blower-vacuums (Figs. 3, 4) were powered at each

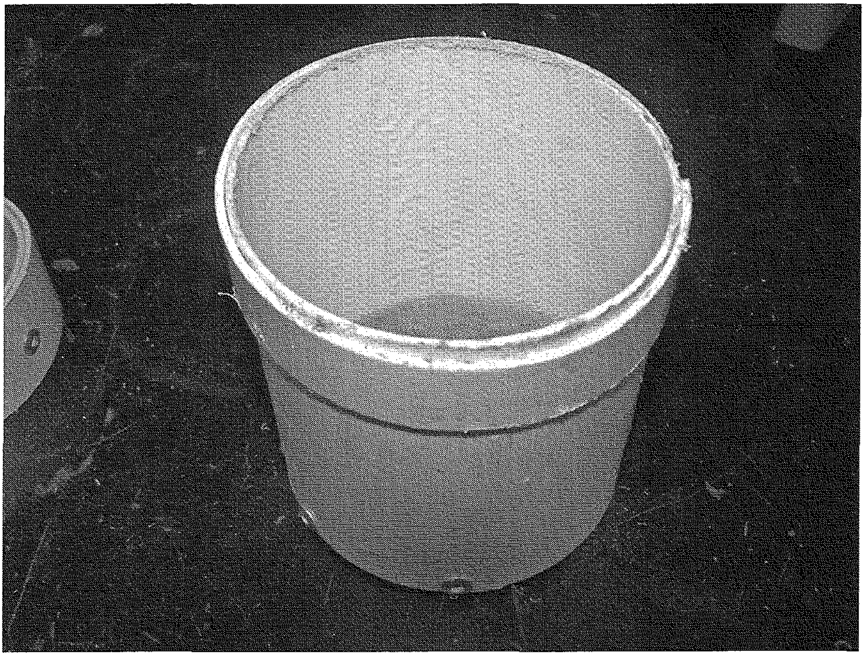

Fig. 2. Screen insert for hand-vacuum.

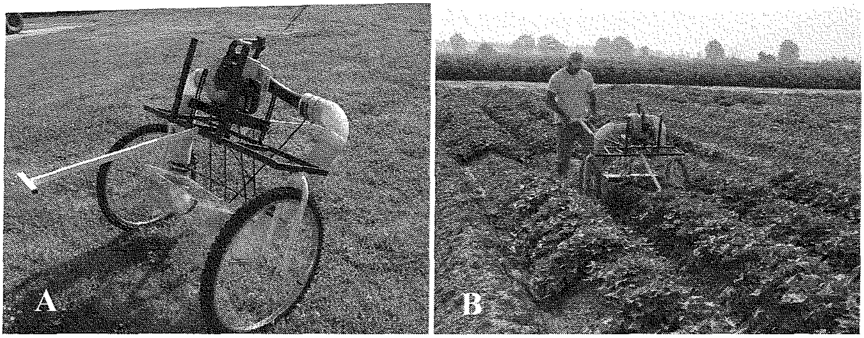

Fig. 3. Blower-vacuum detail (a) and in use (b) as used in the Delta Region study.

location by the same unit as the hand-vacuum, an ECHO Shred 'N' Vac ES-210 (Hill Region study) or an ES-230 (Delta study). Schedule 40 PVC pipe (10.2 cm diam) was used to direct the fan exhaust air across the sweetpotato foliage within a row to blow insects from the foliage into a 20.3 cm diam funnel attached to the PVC pipe connected to the suction port of the fan. A 50-mesh nylon screen inserted in the vacuum port trapped insects (Fig. 5) and facilitated their transfer into a plastic bag for later identification and counting. The blower-vacuums were designed to straddle 1 row and could be adjusted for varying row heights. They were pushed along 7.6 m of row at a speed of approx. 4.3 km/h. Differences in construction of the blower-vacuums used in the Delta study and the Hill Region study included a piece of curved, acrylic plastic (Fig. 3A) on the Delta machine in place of a funnel to help contain and channel insects being blown into the vacuum port. The blower-vacuum used in the Hill Region study had the option to install a dislodge chain (Fig. 4B) that brushed the sweetpotato foliage just in front of the air stream to dislodge insects.

Standard, 38-cm diam, sweep-nets were used by researchers in both the Delta and Hill Region studies. Twenty-five sweeps were made by sweeping back and forth in front of the sampler with the net's rim briskly brushing the foliage while the sampler

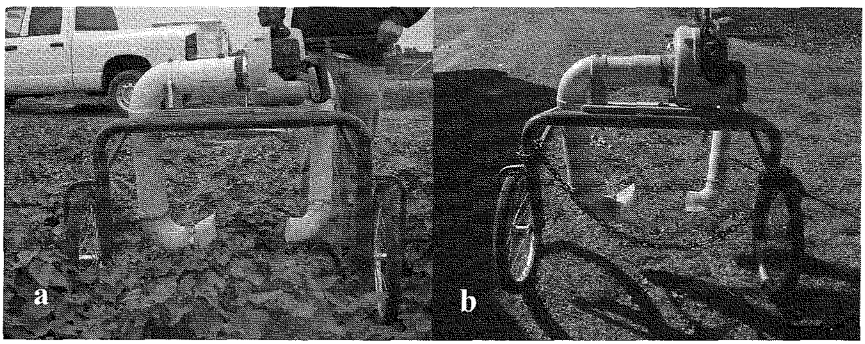

Fig. 4. Blower-vacuum without chain to dislodge insects (a) and with chain (b) used in the Hill Region study.

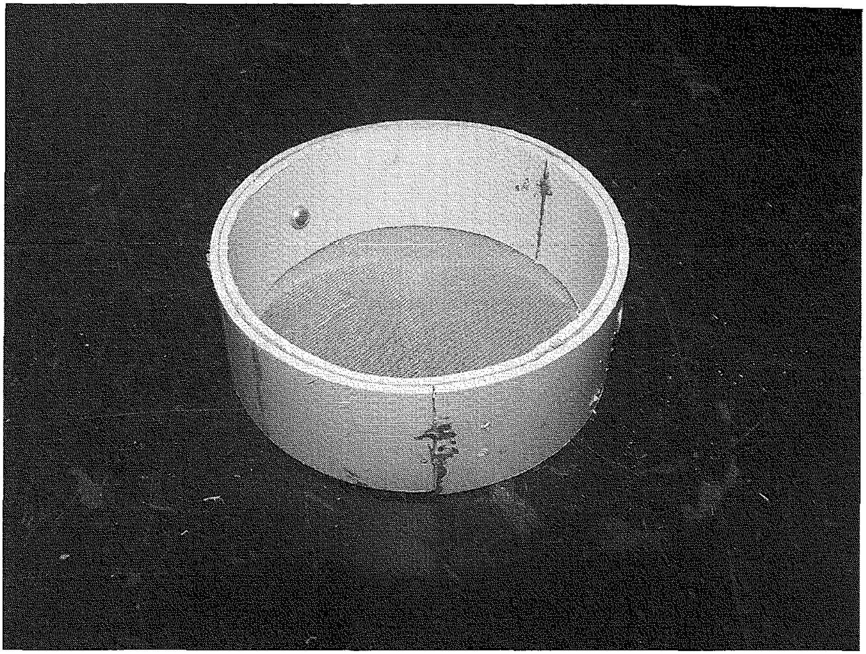

Fig. 5. Screen insert for blower-vacuum.

walked along the row for approx. 12 m. Because sweetpotato foliage is shallow, sweep-net samples could not be made the full width of the sweep-net without hitting the hipped soil. It was estimated that each sweep sampled a swath approx. 30 cm wide and, therefore, 7.6 m of row were sampled with 25 sweeps. Samples taken with vacuum samplers in the same subplots were spatially separated from the row sampled with the sweep-net by a minimum of 2 rows.

Method comparisons. Hand-vacuums and blower-vacuums were compared with each other or with sweep-nets by duplicated samples on the same day and the same general time of the day. Sampling was repeated weekly or at least multiple times. In the Delta study, the hand-vacuum was compared with the sweep-net in 2003 and 2006, to the blower-vacuum in 2004, and to the sweep-net and blower-vacuum in 2005. In the Hill Region study, 1 trial to compare the blower-vacuum, hand-vacuum and sweep-net techniques was completed in a single field in 2003. In 2005, 2 - 4 research plots in each of 24 commercial sweetpotato fields were sampled with both a hand-vacuum and a sweep-net. In the Delta study, all beneficial insect species were recorded simply as beneficial insects. Flea beetles (*Systena* spp., *Chaetocnema* spp. and others) were grouped and counted together, and leafhopper and grasshopper species were grouped and counted in their respective categories. Tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois) also were recorded. In both regions, all lepidopteran larvae were grouped and counted as lepidopteran larvae, and elaterid beetles and tortoise beetles included all species of their respective group. Spotted cucumber beetles were recorded in both regions. Lady beetles

(Coleoptera: Coccinellidae) and bigeyed bugs (Hemiptera: Geocoridae) were the primary beneficial insects recorded in the Hill Region study. *Systena* flea beetles were recorded as a separate group in the hills, and because *C. confinis*, the sweetpotato flea beetle, composed the majority of flea beetles from that genus, all flea beetles of that size were recorded as sweetpotato flea beetles. Sweetpotato flea beetles and *Systena* flea beetles were later combined for some analyses.

Delta study protocol. Sweetpotato plots were planted in Stoneville, Holly Bluff and Mound Bayou, MS, to evaluate planting date, harvest date, and irrigation parameters in 2003 - 2006. These plots were sampled weekly for insects beginning on 9 June 2003, 15 June 2004, 27 June 2005, and 26 June 2006. Sampling methods were treatments that were replicated 3 (2003 - 2004) or 4 (2005 - 2006) times with 4 subsamples per replicate for a total of 30 m with the vacuum samplers or 100 sweeps with a sweep-net per replicate. The same individual took all samples by an individual method for all locations during all 4 yrs of the study. Samples by different sampling methods were separated spatially by at least 2 rows. Hand-vacuum and sweep-net samples were taken weekly for 10 wks in 2003 and 12 wks in 2006. Hand-vacuum and blower-vacuum samples were taken weekly for 10 wks in 2004. In 2005, sweep-net, hand-vacuum and blower-vacuum samples were taken weekly for 7 wks. The sweetpotato crop at each location was managed as a commercial crop with appropriate tillage, herbicide and insecticide applications applied to the entire research area. Thus, insect samples taken with different sampling methods were all taken in sweetpotato foliage receiving the same management inputs.

Data were analyzed using SAS statistical software version 9.1 (SAS Institute Inc., Cary, NC). Significant parameters and interactions were determined by analysis of variance (GLM, mixed procedure, REML estimation method, Prosad-Rao-Jecke-Kacker-Harville SE method, and Kenwood-Roger degree of freedom method) with all parameters fixed. Data for each insect or insect group were then analyzed using the mixed model procedure with location and year as random variables, and with location as random variable for determination of differences between treatment means within years using paired-t analysis ($P = 0.05$) of the differences between least squares means for each sample type. Data were transformed to the log10(x+1) prior to analysis.

Hill Region study protocol. In 2003, a trial comparing sweep-net, hand-vacuum and blower-vacuum samples was completed using a randomized complete block design with 8 replicates and 3 subsamples per replicate (Reed and Williams 2004). The trial was established in a commercial field of sweetpotatoes (var 'Beauregard') where vines were well established and covered the middles. In each replicate, samples were taken from 12.2 m of row, repeated along the length of the row until 3 subsamples were completed. Samples by each method within a replicate were spatially separated from samples with other methods by an 8-row buffer. Treatments were sweep-net, hand-held vacuum sampler, and blower-vacuum with and without a chain to dislodge insects from the foliage. Each sampling method sampled 12.2 m of row, and sweep-net samples were 25 sweeps over the 12.2 m distance with the net briskly brushing the foliage. The data were reanalyzed for this report using the mixed procedure with replicates as a random variable.

In 2005, each of 23 commercial sweetpotato production fields was planted with a strip 12 - 16 rows wide by 91 m long without insecticide. In each field another strip of the same size, usually adjoining the no-insecticide strip, received preplant incorporated insecticide and any foliar insecticide applied to the rest of the field during the season. In 4 of the fields, an additional strip of the same size received only the preplant incorporated insecticide or only insecticides applied to foliage during the season. Each of these plots (hereafter called strips) was divided into 6, 15.25 m subplots. There were not enough hand-vacuums to sample every field every week by that sampling method but, when possible, each subplot within a field was sampled with a hand-vacuum and a sweep-net. Eight different individuals conducted the sampling, with 3 samplers doing most of the sampling. Samples were taken in each field beginning about 2 wks after planting. The week of the year in which the samples were made was recorded to evaluate data trends and interactions with time.

Data from the Hill Region study were transformed by the log transformation (log10[X+1]) and averaged across subsamples within strips prior to analysis. Significant parameters and interactions were determined by analysis of variance (GLM, mixed procedure) with all parameters fixed as in the Delta study. Data for each insect or insect group were then analyzed by using the mixed model procedure with field and strip as random variables to determine differences between treatment means at the 95% level of probability ($P = 0.05$).

Results

Insects collected from the 2 different regions of Mississippi differed considerably and appeared to reflect the influence of major crops in each of the 2 areas. Insect numbers for insect species or groups injurious to sweetpotatoes other than flea beetles, which were collected in both locations were slightly higher in the Delta Region samples as compared with Hill Region samples (Fig. 6). The high numbers of flea beetles in the Hill Region study may be a result of long-term sweetpotato production. Because the sweetpotato flea beetle, *C. confinis*, which feeds primarily on sweetpotatoes and morning glories (Balsbaugh and Hays 1972, Clark et al. 2004), and flea beetles of the genus *Systena* have long been recognized as pests of sweetpotatoes and are not considered pests of other row crops in the state. Conversely, lepidopteran larvae that would likely be associated with 1 or more alternate crops were far more numerous in the Delta area. Other insects recorded during sampling also differ considerably between regions. Tarnished plant bug and *Phyllophaga* adults were collected frequently in the Delta, but were so infrequently collected in the Hill samples that their numbers were not recorded. The Hill Region had more hectarage of sweetpotatoes in close proximity with wild host plants and fewer hectares of corn, soybeans and cotton than in the Delta. It was likely that these factors impacted the numbers of these insects found in sweetpotatoes in the 2 regions.

Delta Region. The first 2 wks of sampling resulted in numerous samples with no insects or with few insects; therefore, data for the first 2 wks of sampling (taken from recently planted slips) were omitted from the analyses. Insect numbers differed across years, and year by sampling method interactions were significant for all insects (Table 1). Data were analyzed by year with location and replicate as random variables to determine differences in the number of insects sampled with hand-vacuum, blower-vacuum and sweep-net methods. Because a sweetpotato crop grows rapidly, interactions between sample type and the week of sampling also were examined. Analysis by year with location and replicate as random variables resulted in significant interactions of sample type and week of sampling for 3 insect groupings for 2003, 5 groups for 2004, 4 in 2005, and 3 in 2006 (Table 2). This indicated that as the plants matured and the vines spread, efficacy of 1 or more sample types changed for some insect species relative to the number of insects sampled during the course of the season.

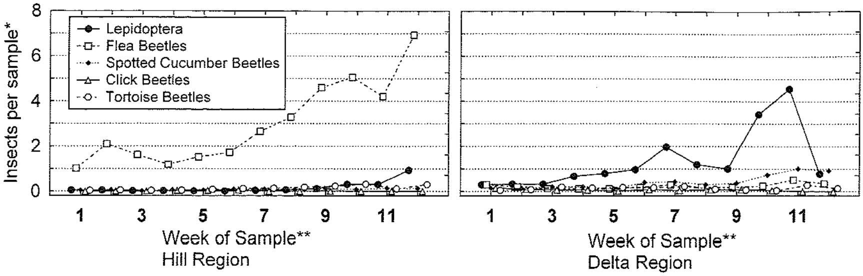

Fig. 6. Insect population trends reflecting mean insects per sample averaged over sample types, regions and years of study. Sampling was begun as soon as plants were established in the field, approximately 2 weeks after sweetpotato slips were set in each field. *Insects per 25 sweeps or 7.6 row-m with vacuum sampler. **Weeks were numbered beginning with the week of first sample relative to each field.

Significant ($P \leq 0.05$) or nearly significant ($P \leq 0.1$) week x sample-method interactions occurred during 2 yrs with lepidopteran larvae, and grasshoppers, 3 yrs with leafhoppers and tarnished plant bugs, and only 1 yr with other insect groups. Thus, the interaction between week of sample and sample method was not consistent within insect groups during the course of the study and suggests weak relationships that occur only sporadically. For example, grasshopper numbers increased in hand-vacuum samples relative to sweep-net samples the last weeks of 2003, but the inverse occurred in 2006 (Fig. 7). The number of lepidopteran larvae in sweep-net samples in 2003 and 2005 decreased during late season compared with the hand-vacuum samples, and beneficial insect numbers in hand-vacuum samples fluctuated

Table 1. Probability of significant F statistic for year*sample-method interaction for mean number of insects collected in the Delta Region study.

Insect / Insect group	df	*F*	Prob. *F*
Beneficial Insects	3, 39.8	12.61	<0.0001
Spotted Cucumber Beetles	3, 38.0	12.12	<0.0001
Click Beetles	3, 37.8	13.45	<0.0001
Flea Beetles	3, 69.0	4.81	0.0042
Grasshoppers	3, 40.8	10.75	<0.0001
Leafhoppers	3, 42.7	7.1	0.0006
Lepidopterous Larvae	3, 37.8	6.43	0.0013
Tarnished Plant Bug	3, 37.5	12.32	<0.0001
June Beetles	3, 35.8	23.20	<0.0001
Tortoise Beetles	3, 42.2	6.78	0.0008

Type III ANOVA, all effects fixed, log transformed data.

Table 2. Probability of significant F statistic for interaction of week of sample x sampling method. Delta Region study, years 2003 - 2006.

	2003			2004			2005			2006		
Insect Grouping	df	*F*	Prob. *F*	df	*F*	Prob. *F*	df	*F*	Prob. *F*	df	*F*	Prob. *F*
Beneficials	7, 120	1.84	0.0863	7, 120	**2.96**	**0.0074**	8, 154	0.79	0.611	9, 209	0.42	0.924
Lepidopterous Larvae	7, 120	**3.61**	**0.0015**	7, 126	1.46	0.1887	8, 154	**4.05**	**0.0002**	9, 209	0.90	0.5257
Tarnished Plant Bugs	7, 120	2.0	0.0603	7, 126	1.49	0.1768	8, 154	**2.09**	**0.0402**	9, 209	**2.30**	**0.0117**
Leafhoppers	7, 120	**4.63**	**<0.0001**	7, 126	0.73	0.0644	8, 154	**2.21**	**0.0299**	9, 209	**8.96**	**<0.0001**
Flea Beetles	7, 126	1.32	0.2456	7, 120	**6.52**	**<0.0001**	4, 154	1.25	0.2749	9, 220	1.02	0.4257
Spotted Cucumber Beetles	7, 126	1.46	0.0773	7, 120	**6.69**	**<0.0001**	4, 154	0.40	0.9219	9, 209	1.12	0.3473
Click Beetles	7, 126	1.13	0.3468	7, 126	**2.68**	**0.0129**	8, 154	1.31	0.244	9, 209	1.03	0.4189
Grasshoppers	7, 126	**2.75**	**0.0109**	7, 126	1.77	0.0995	8, 154	1.38	0.2101	9, 209	**3.30**	**0.0009**
June Beetles		1.88	0.0794	7, 120	**8.19**	**<0.0001**	8, 154	1.24	0.2780			
Tortoise Beetles	7, 126	1.16	0.3338	7, 126	1.30	0.2536	8, 154	**2.45**	**0.0159**	9, 209	1.61	0.1135

Values in bold print indicate significant interactions, $P \leq 0.05$.

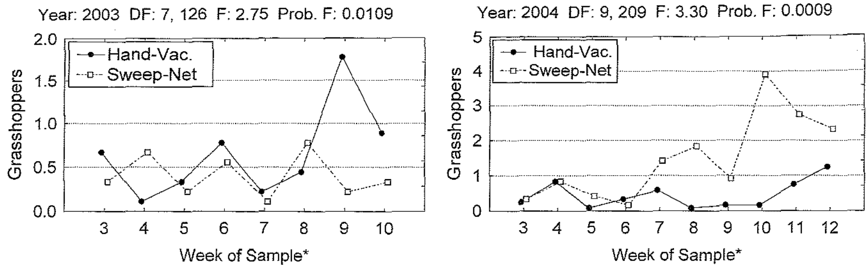

Fig. 7. Significant sample-method*week of sample interactions for mean number of grasshoppers per sample suggesting reversed efficacy of the 2 sample methods late season for 2003 and 2004. Delta Region study. *Weeks were numbered beginning with the week of first sample relative to each field.

considerably with a steep decline late season relative to that of blower-vacuum samples in 2004 (Fig. 8). Interactions that occur within an insect grouping for more than 1 yr strengthen the supposition that the interactions in those insect groups are meaningful. This occurred with tarnished plant bugs (Fig. 9) and leafhoppers, based on 2 or more years with significant interaction, where the number of insects in sweep-net samples were generally less than those in hand-vacuum samples early in the season, but equaled or exceeded those in hand-vacuum samples later in the season.

Of the week x sample-method interactions with hand-vacuum and blower-vacuum factors that were significant for only a single yr, numbers of flea beetles, cucumber beetles, and tarnished plant bugs were similar in early season samples, but changed during the season with hand-vacuum sample numbers increasing relative to blower-vacuum samples later in the season. The opposite was true where beneficial insect numbers (2004) and leafhopper numbers (2005) in hand-vacuum samples decreased over time relative to blower-vacuum samples.

Hand-vacuum samples collected significantly more insects than sweep-net samples a majority of the time (2 of 3 yrs) for lepidopteran larvae, tarnished plant bugs, and spotted cucumber beetles and for 1 yr for beneficial insects, flea beetles, click beetles and tortoise beetles (Table 3). The blower-vacuum collected significantly fewer insects of all species than the hand-vacuum in 2004. In 2005, there were no significant differences between click beetle or tarnished plant bug numbers collected with the 3 methods, but insects in blower-vacuum samples were significantly lower than numbers collected in hand-vacuum and sweep-net samples for beneficial insects, leafhoppers, flea beetles, cucumber beetles and tortoise beetles and lower than hand-vacuum samples of lepidopteran larvae. The sweep-net counts of grasshoppers were significantly higher than those of other sampling methods in 2005, and higher than the hand-vacuum counts for lepidopteran larvae and grasshoppers in 2006. Mean insects per sample for each sampling method for sweetpotato pests over the 4 yr study indicate that the general efficacy of the 3 sampling methods in the Delta study were hand-vacuum>sweep-net>blower-vacuum. Even though these samples were taken by the same individual using the same sampling techniques over the 4-yr period, there were several instances when results differed between years for the same insect.

Weekly sample means of beneficial insects and sweetpotato insect pests averaged across years suggest a similarity between sweep-net and hand-vacuum samples for

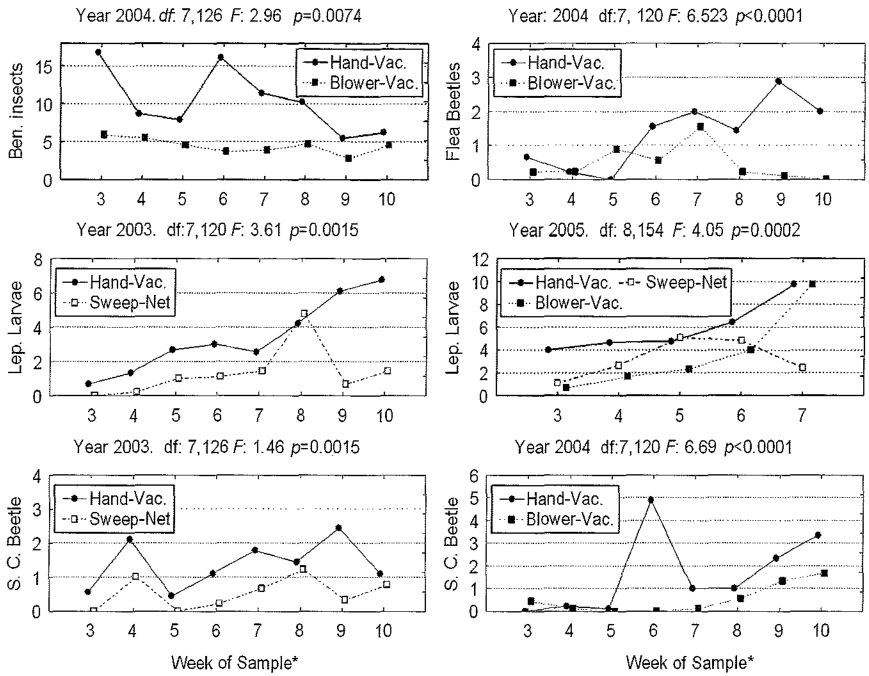

Fig. 8. Significant sample-method*week of sample interactions of mean number of insects per sample for beneficial insects and insects considered damaging pests of sweetpotatoes. Delta Region study. *Weeks were numbered beginning with the week of first sample relative to each field.

all insects except click beetles and flea beetles, in which case the hand-vacuum was superior to the sweep-net (Fig. 10). The blower-vacuum collected fewer insects than other methods for all insects sampled. With the exception of click beetles, there was a trend for sweep-net samples to increase in efficacy relative to hand-vacuum samples

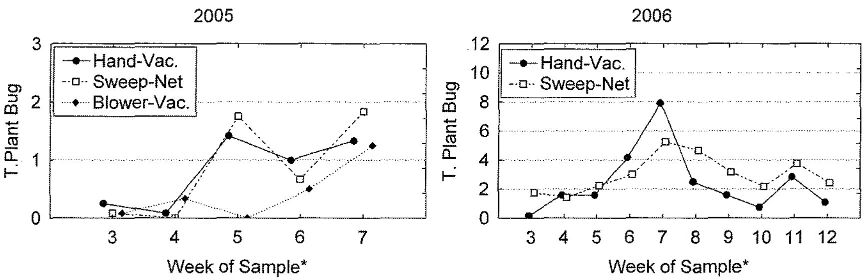

Fig. 9. Mean tarnished plant bugs per sample for different sample methods for 2005 and 2006 in the Delta Region study. *Weeks were numbered begin-

able 3. Mean* insects per sample from sweetpotatoes in the Mississippi Delta Region study averaged from week 3 to end of season.

ear	Sample Method	Beneficial Insects	Lepidopterous Larvae	Tarnished Plant Bugs	Leaf-hoppers	Flea Beetles	Spotted Cucumber Beetle	Click Beetles	Grass-hoppers	June Beetles	Tortoise Beeetles
003	Hand-Vacuum	1.96 a	2.30 a	1.07 a	1.03 a	0.67 a	0.89 a	0.64 a	0.43 a	0.37 a	0.31 a
	Sweep-Net	1.29 b	0.77 b	0.76 a	1.36 a	0.23 b	0.39 b	0.11 b	0.28 a	0.06 b	0.22 a
	Prob. *F*	00.0162	<0.0001	0.0621	0.1145	0.0004	0.0002	<0.0001	0.1021	<0.0001	0.2589
004	Hand-Vacuum	9.00 a	2.54 a	2.40 a	2.57 a	0.94 a	0.94 a	0.27 a	0.78 a	0.09 a	0.44 a
	Blower-Vacuum	3.69 b	0.77 b	0.56 b	1.42 b	0.29 b	0.33 b	0.03 b	0.39 b	0.00 b	0.06 b
	Prob. *F*	<0.0001	<0.0001	<0.0001	0.0005	<0.0001	<0.0001	<0.0001	0.0153	0.0006	<0.0001
005	Sweep-Net	2.60 a	2.06 b	0.46 a	2.93 a	0.18 a	0.66 a	0.05 a	0.51 a	0.01 a	0.56 a
	Hand-Vacuum	3.15 a	3.95 a	0.49 a	2.66 a	0.13 a	0.77 a	0.05 a	0.18 b	0.03 a	1.04 b
	Blower-Vacuum	1.55 b	2.08 b	0.26 a	1.51 b	0.01 b	0.40 b	0.04 a	0.15 b	0.00 a	0.28 c
	Prob. *F*	<0.0001	<0.0001	0.0843	0.0038	0.0265	0.0415	0.8472	0.0013	0.2915	<0.0001
006	Sweep-Net	8.10 a	4.73 a	1.38 a	1.44 a	0.43 a	0.04 a	0.06 a	0.79 a	—	0.42 a
	Hand-Vacuum	7.19 a	3.33 b	1.94 b	1.88 a	0.61 a	0.07 b	0.11a	0.26 b	—	0.28 a
	Prob. *F*	0.1230	0.0030	0.0102	0.0948	0.1569	0.0016	0.1693	<0.0001	—	0.0631

eans within a column and year not sharing a common letter differ significantly (difference between least means; $P = 0.05$).
/leans back-transformed from the log(x+1) transformed data.

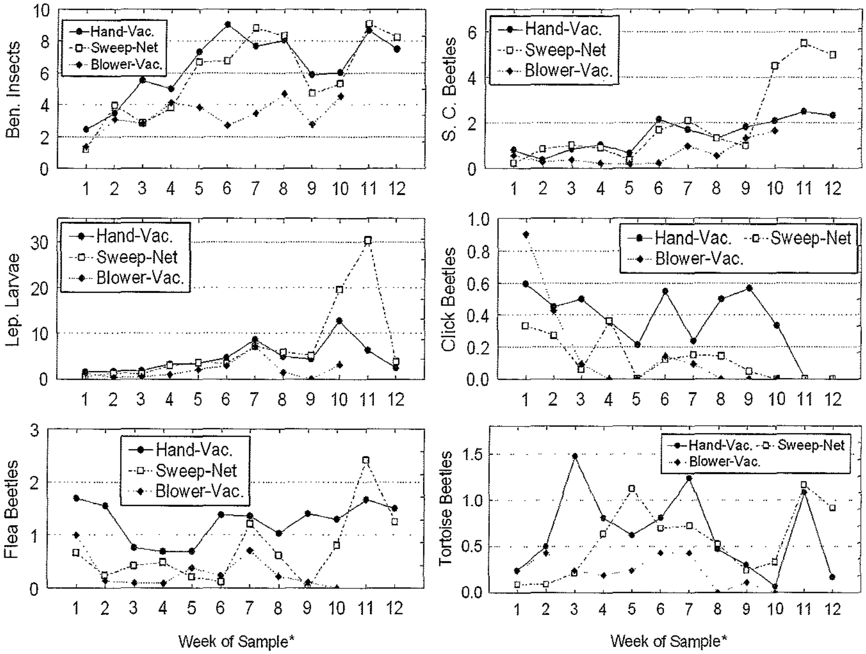

Fig. 10. Mean insects per sample for 3 sample methods in the Delta Region study averaged across 4 years. *Weeks were numbered beginning with the week of first sample relative to each field.

late in the season. In view of these facts and the inconsistent week x sample-method interaction patterns among the sweetpotato pests over the 4-yr study, it appears that either sweep-net or hand-vacuum sampling methods would be acceptable for all sweetpotato pests, beneficial insects and miscellaneous insects. Two exceptions may be click and flea beetles for which the hand-vacuum may be superior to the sweep-net.

Hill Region. In the season-long trial in the Hill Region, 9 individuals were involved in sampling the plots in 24 commercial sweetpotato fields, but 3 specific individuals did most of the sampling. Four of the 9 individuals sampled on few dates, sampled only a single field, or sampled with only 1 sample type. Thus, when individual was used as part of the error term, degrees of freedom were so severely limited that analyses were generally meaningless. Because most of the sampling was done by 3 individuals, and because all but 1 of the other individuals' results were similar to that of the 3 primary individuals, it was assumed that sampling was relatively uniform and individual sampler was ignored in analyses. Although insecticide treatment strip or interactions involving strip were never significant for any of the insects collected, strip was nearly significant ($P = 0.09$) for lady beetle numbers, and the strip x sample method interaction was nearly significant ($P = 0.20$) for sweetpotato flea beetle and tortoise beetles (Table 4). To avoid oversimplifying the model, strip was included with field as a random variable in analyses. Analysis of the difference between insect counts (mean

Table 4. Significant effect and interactions and those with probability less than 0.2 of sampling method with treatment strip* or week of sample resulting from the Mississippi Hill Region study in 2005.

	Fixed Effect	df	*F*	Prob. *F*
Lady Beetles	Strip x Sample method	2, 73	1.75	0.1802
	Strip	2, 75	1.97	0.0886
Sweetpotato Flea Beetle	Strip x Sample Method	2, 111	3.91	0.1759
Tortoise Beetles	Strip x Sample Method	2, 124	1.74	0.1792
Bean Leaf Beetle	Sample Method x Week	5, 167	1.55	0.1773
Lady Beetles	Sample Method x Week	5, 194	3.80	0.0026
Sweetpotato Flea Beetle	Sample Method x Week	5, 212	6.85	<0.0001
Systena Flea Beetles	Sample Method x Week	5, 192	4.45	0.0007
Tortoise Beetles	Sample Method x Week	5, 196	5.48	<0.0001
Lepidoptera Larvae	Sample Method x Week	9, 210	1.00	0.1428
Bigeyed Bugs	Sample Method x Week	5, 201	3.30	0.0068
Spotted Cucumber Beetle	Strip x Sample Method x Week	9, 206	1.60	0.1162
Click Beetles	Sample Method x Week	5, 241	1.69	0.1376

*Treatments of (1) farmer's insecticidal regimen; (2) no insecticide; (3) preplant- incorporated insecticide [some fields]; (4) foliar insecticides [some fields].
Type II ANOVA, all effects fixed, log transformed data.

first 2 wks of sampling in the 2005 study resulted in no significant differences for any insect sampled. As with the Delta study, analyses were restricted to means of insect samples from week 3 to the end of the season. The sweep-net collected significantly more insects than the hand-vacuum for every insect or insect group except click beetles for the period from week 3 to the end of the season (Table 5).

Based on insects collected beginning week 3, a significant sample week versus sample method interaction was evident for 5 of the 8 insects or insect groups recorded (lady beetles, sweetpotato flea beetles, tortoise beetles, *Systena* flea beetles, and bigeyed bugs) (Table 4). The typical interaction is a mid to late-season increase of numbers of insects caught in sweep-nets relative to those caught in hand-vacuums (Fig. 11).

Table 5. Mean number of insects (±SE) per 25 sweeps or vacuum samples from 7.6 row-m of sweetpotato foliage in the Mississippi Hill Region study averaged from week 3 to end of season.

Insect	Sweep-Net	Hand-Vacuum	Prob. *F*
Bigeyed Bug	0.34a ± 0.0524	0.12b ± 0.0526	0.0037
Sweetpotato Flea Beetle	7.90a ± 0.1568	2.24b ± 0.1572	<0.0001
Lady Beetles	1.06a ± 0.1686	0.82b ± 0.1686	0.0048
Spotted Cucumber Beetle	0.26a ± 0.0408	0.07b ± 0.0410	0.0019
Systena Flea Beetles	0.88a ± 0.0840	0.30b ± 0.0842	0.0023
Tortoise Beetles	0.39a ± 0.0798	0.17b ± 0.0800	0.0126
Lepidopterous Larvae	0.18a ± 0.0473	0.05b ± 0.0475	0.0354
Bean Leaf Beetle	0.24a ± 0.0412	0.07b ± 0.0413	0.0022
Click Beetles	0.03a ± 0.0142	0.01a ± 0.0143	0.3213

Means back transformed from the log10(x+1) transformation.
Means within a row not sharing a common letter differ significantly (difference between least squares means; $P = 0.05$).

In the 2003 trial, sweep-net samples of spotted cucumber beetle were significantly higher than those taken with a hand-vacuum, but samples of these 2 methods were equivalent for sweetpotato flea beetles and tortoise beetles (Table 6). The blower-vacuum samples in this trial were taken with and without a chain hung from side to side just in front of the blown air stream. The number of the 3 insect species in samples taken without the chain was generally larger than that taken with the chain, and flea beetle and tortoise beetle numbers were significantly larger than numbers collected with the chain. Additionally, blower-vacuum samples without the chain were significantly larger than those of sweep-net for flea beetles and tortoise beetles, and larger than hand-vacuum samples for tortoise beetles.

Discussion

Overall results of this study strongly suggest that the sweep-net is the method of choice for sampling insects in the foliage of sweetpotato. Results of the replicated trial comparing sweep-net, hand-vacuum and blower-vacuum in 2003 were not entirely consistent with these findings. Because insects may react differently to time of day, wind, temperature and humidity conditions by moving up or down in the crop canopy, it is possible that efficacy of each sample technique may be altered with changing conditions or time of sample. Where these conditions change for much of the season as in an extended period of drought or rain, sampling results might be altered for 1 or more sample types for long periods of time and might explain some of the differences within insect species between years. Subtle differences in sampling devices and sampling technique also probably affected results. The protruding steel 'T' on the front of the Delta blower-vacuum (Fig. 1), designed to rest on the ground when the machine is leaned forward, may have drug the top of the leaves as the machine was pushed along the row. During the course of this study, we noted that spotted cucumber beetles

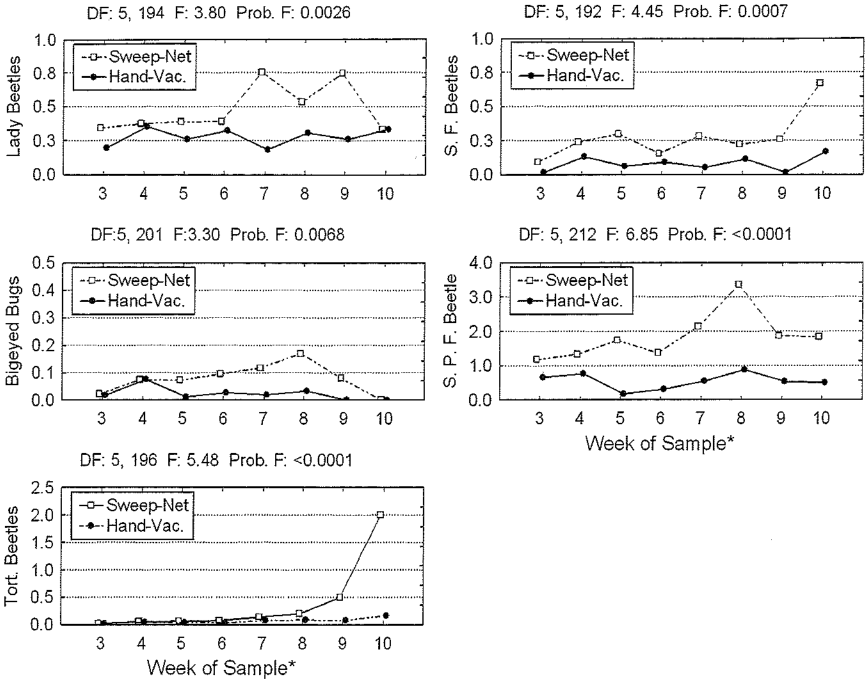

Fig. 11. Significant sample method*week of sample interactions for mean insects per sample in the Hill Region study. Means were back transformed from the log10(x+1) transformed means. *Weeks were numbered beginning with the week of first sample relative to each field.

and whitefringed beetles drop from the foliage at the slightest disturbance. Thus, anything brushing the foliage in front of the air stream of the blower-vacuum, such as the 'T' (Fig. 1, 2) or the chain (Fig. 4B), would likely reduce efficacy by dislodging insects before the air stream could blow them into the vacuum port of the sampler. Vacuum samplers also suck up leaves that are either on the ground or about to be shed from the plant. When this occurs, the leaf blocks much of the air from the suction tube, and the vacuum's engine increases noticeably in revolutions per minute indicating blockage. Instructions to operators included the removal of leaves from the collection screen when engine RPM's suddenly increased. In real-world sampling, where heat, humidity and fatigue become factors of a sampler's day, this kind of instruction would tend to be ignored, resulting in reduced numbers of insects captured in vacuum samples.

The fact that the hand-vacuum and blower-vacuum required samplers to operate a gasoline engine makes the assumption that all who use the device can adjust the carburetors and set the throttle control for maximum revolutions per minute, and also assumes that these devices are always functioning optimally. In reality, these devices do not operate continually at optimal revolutions per minute. Inhibitive carbon build up on exhaust ports of 2-cycle engines over time negatively affects engine function and mandates periodic cleaning of the exhaust ports by a qualified mechanic. Differences

Table 6. Mean (±SE) insects in 25 sweeps or 7.6 row-m of vacuum sample resulting from the 2003 Mississippi Hill Region study.

Sample Method	Sweetpotato Flea Beetle	12 Spotted Cucumber Beetle	Tortoise Beetles
Hand-Vacuum	3.83ab ± 0.454	0.29b ± 0.133	3.04b ± 0.385
Sweep-Net	3.17b ± 0.267	0.96a ± 0.239	3.04b ± 0.278
Blower-vacuum with chain	2.88b ± 0.454	0.25b ± 0.104	3.58b ± 0.349
Blower-vacuum without chain	4.67a ± 0.480	0.50ab ± 0.167	7.00a ± 0.601
Prob. *F*	0.0158	0.0276	<0.0001

Means within a column not sharing common letters differ significantly (difference between least squares means; $P = 0.05$).

in fuel octane, fuel additives, fuel alcohol content and other factors such as air filter quality or cleanliness would all play a role in vacuum efficacy. In view of the results of these studies and the inherent technicalities associated with the vacuum devices used in this study, sweep-nets are recommended as the sampling method of choice for insects associated with sweetpotato foliage.

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